

Theologians and scientists share the aspiration of obtaining a deeper understanding of life and the nature of the universe. They agree that this understanding should be based on information--the more the better. We've acquired lots of information about living things and physical forces in the last few years. This information must and will have a profound effect on everyone's thinking. I'd like to summarize some of this recent information from the area of molecular biology and the impact it has upon three specific questions that I wish to pose. These questions are:

- 1) What is meant by the terms life or living?
- 2) Are mental processes too complex for understanding at a molecular level?
- 3) Even if mental processes are understood at a molecular level, are science and technology adequate to guide human behavior? In and around this question are interwoven the many doubts and convictions of how necessary religion is as a guide to the human spirit.

1. What is meant by life or living? A proper definition of living things was a popular indoor sport 20 years ago. I'm impressed at how much less concerned informed people are about this today. At the rate modern biology is being taught and assimilated, I'd be surprised if this were a suitable question for discussion by intelligent people 20 years from now.

The acquisition of the information regarding this question is so recent that I'd like to cite a few incidents in the history of science to provide some perspective.

Not very long ago man was so ignorant about thunder, lightning and rain, about meteors, stars, the sun and the moon, that he had a large assortment of gods and goddesses to help him encompass all these phenomena and bodies in some rational way. Later on the origin and interrelationships of these various entities in nature were understood well enough to warrant cutting down on the number of deities. I don't want at this point or at any subsequent point to appear smug or to second-guess our ancestors of ~~Several Thousand~~ ~~2,000~~ years ago. If we knew only what they did we'd think and behave exactly the same way.

Some more recent and specific examples might better illustrate this point.

Aristotle had believed that life could be generated spontaneously from nonliving things. Given the "right" conditions, an "active principle" in some bit of matter would develop into some particular creature. To quote him:

"Such are the facts, everything comes into being not only from the mating of animals but from the decay of earth. And among plants the matter proceeds in the same way, some develop from seed, others, as it were, by spontaneous generation by natural forces; they arise from decaying earth or from certain parts of plants."

~~In the 13th century~~ ^{1300 years later} people believed geese originated from certain fir trees that had come into contact with ocean water. In the 16th century Paracelsus, an outstanding physician and chemist ~~and~~ to whom some historians ascribe the discovery of hydrogen, also described a series of observations on the spontaneous generation of mice, frogs, eels and turtles from water, air, straw and decaying wood among other things. A century later (only 300 years ago) van Helmont, a Belgian who performed really excellent experiments in plant physiology, also came up with a sure-fire recipe for producing mice in 21 days. Take a dirty (sweaty) shirt and incubate with kernels of wheat for 21 days. Baby mice emerge.

You all know that when the control experiment of incubating the shirt and wheat in a box was done 100 years later, it set this matter straight. But then the controversy started all over again with respect to microbes. It wasn't until Pasteur that this matter was set straight. That was only 100 years ago! It might not have been settled even then if it weren't for the incredible genius of Pasteur's experiments ^{and} the force of his personality. Yet Pasteur was a devoutly religious man. I gather that he was willing to accept and believe things that even Spanish bishops would find hard to swallow today.

In preparing these notes a week ago I came across the following item in Herb Caen's column written from Mexico City.

"In spite of the tender ministrations of the Church these many centuries, superstition lives on in this legendary land. At the entrance to the magnificent new Museum of Anthropology stands a huge statue of a pre-Columbian rain god

which had stood for close to a thousand years in a tiny village. When the Government announced it was moving the idol to Mexico City, the natives rebelled so violently that troops had to be called. On the day the rain god was installed at the museum there was a violent deluge--the first recorded rainfall on that date in Mexico City records. Nobody was particularly surprised.

We lunched the other day with a Mexican executive who had been born in Yucatan. "I am not a superstitious man," he said, "but recently my baby became mysteriously ill with a very high fever. We had three doctors. None could cure her. So I bundled her up and flew to my home town in Yucatan. The witch came and rubbed an egg--still in its shell--all over her body. Then she broke the egg into a saucer and placed it under the bed. The next morning my baby's fever was gone. And the egg under the bed was cooked. Naturally, I don't believe in witchcraft, but" And he shrugged. "

In 1828, the belief was firmly held that the molecules produced by living things were fundamentally different from anything the chemist could assemble from non-organic sources. This idea that there was something vital about an organic molecule was exploded by Wohler's synthesis of urea. He succeeded in synthesizing this molecule, previously known only to be obtained from urine, from the simple inorganic reactants CO_2 and NH_3 . Once this belief was shattered, a rapid succession of more and more complicated organic molecules were synthesized. Chlorophyll, morphine and sex hormones are synthesized by chemists from scratch. Synthesis of simple proteins and nucleic acids stopped making newspaper headlines two years ago. It should be clear from this that molecules, no matter how complex, are not distinguishable in any fundamental way from simple gases which serve as their precursors.

In 1935, Wendell Stanley was purifying the virus responsible for mosaic disease in tobacco leaves. To his amazement the preparation

crystallized as if it were some salt or simpler organic compound. Within 20 years it became clear that the tobacco mosaic virus is in essence a molecule consisting of a single nucleic acid molecule of fixed composition enveloped by a fixed arrangement of 2,000 protein molecules each of precise composition. The protein serves as a protective overcoat in nature for the nucleic acid. The relatively small and simple nucleic acid molecule, if artificially introduced into a tobacco leaf, is quite sufficient to initiate and direct the synthesis and assembly of many complete viruses which can go on to infect other plants. I doubt that there are any major chemical surprises left in the tobacco mosaic virus. Soon the arrangement of all the atoms in the nucleic acid and the protein will be known and later on they will be synthesized from simple precursors. Whatever life-like attributes this virus has, they no longer seem strange or particularly distinctive to the chemist.

Viruses like the TMV are, as you know, far from being cells. They are streamlined and stripped down to the point of being totally incapable of propagating themselves in nature. They must rely on entering a cell which has the elaborate machinery to supply the chemical energy and specialized building blocks to synthesize the viral nucleic acid and protein. A favorite place for us to study viral infections is in bacteria. No one doubts that bacteria are alive with individualities that require encyclopedias for description.

All viruses are not as simple as the TMV nor are all bacteria complex enough to be able to fully sustain themselves and propagate in very simple media. Recent studies reveal that there is a broad and continuous spectrum of virus types from apparently simple rods and spheres to rather formidable looking creatures. We work a good deal with a bacterial virus called T2. Twenty years ago it was a tiny glob barely visible in the electron microscope of that day. Today it is known to have a complex polyhedral head skillfully packed with DNA, a neck piece, a tailpiece, tail fibers and elaborate joints and fittings which make this creature about as imposing at a glance as a tarantula. This spectrum of increasing viral complexity blends almost imperceptibly with the relative simplicity of the rather small streamlined bacteria. I'm confident that further investigation of the complex viruses and simpler bacteria will blur any dividing lines into oblivion.

If you think the little rods and spheres called bacteria are simple, forget it. Twenty years ago Escherichia coli, the modern biochemist's guinea pig, was just a little rod. Then in 1945 Lederberg and Tatum discovered it had sex. While it was Americans who discovered sex in bacteria, it was Frenchmen who learned how to exploit it. A rather thick book appeared two years ago by Francois Jacob and Elie Wollman of the Pasteur Institute entitled "Sexuality and the Genetics of Bacteria." The book appeared too late to include some elegant photographs of projections from the male types of E. coli that very likely serve as their copulative organs.

You may be accustomed to seeing bacteria as individual little animalcules. This is how we try to distribute them in liquid cultures for optimal

growth rate or spread them on slides for convenient viewing. In nature or left to their own devices they form socially advantageous colonial arrangements. Their cell surfaces, about which we know too little, are intricately designed for interaction with other cells. Certain bacterial species which resemble fungi develop complex structures in which certain of them serve as a base, others as a stalk and still others as a sort of fruiting body at the top. It really isn't too far-fetched to compare the social organization of these cells to the multicellular organizations which we call higher plants and animals. A comparable extrapolation from societies of ants and bees to the society of man is too common to dwell upon.

Suppose it were true then that the whole range of living things starting from CO_2 , H_2O and NH_3 ^{was} ~~were~~ one indistinguishable continuum of molecular arrangements, we are still faced with the problem of how this remarkable spectrum was created!

This last Christmas period I had the leisure to read and review a biology textbook with my youngest son, a freshman at Woodside High School. This is the blue book in the ^{BSC} ~~AIB~~ curriculum: From Molecules to Man. I was most impressed with its organization, content and ambitions. When we got to the section on the theories of evolution I asked Ken whether they'd actually read "Origin of Species." "No, we haven't read the book," he said, "but we've seen the movie."

If there were any lingering doubts about natural selection as the basis for the origin of new species and the reproduction of existing species, they must be dispelled by the information acquired in the past few years. It's strange how persistent the opposition to Darwinian evolution has been. In

Russia it survived the revolution, then Stalinism and later the systematic eradication of Stalinism. It is only during the last few months, since Khrushchev's deposition, that sanity is being restored to biology and genetics in the Soviet Union. I gather there are many communities in the U. S. whose school boards still violently oppose the teaching of evolutionary hypotheses.

Why are we now more firmly convinced of the essential validity of the evolutionary process? To put it briefly, we know the chemical nature of the gene to be DNA. DNA as the genetic substance is responsible for 2 things: For one, it contains all the information to produce the enzymes of the cell which in turn are responsible for the entire machinery of the cell. By dictating the specific nature of every protein in the cell, the DNA determines what the cell looks like and every aspect of its operations. This is the phenotypic function of the DNA, the function that determines the physical makeup of every cell. The second thing for which DNA is responsible is its capacity to act as a template for producing a second copy of the DNA absolutely identical to itself. This second copy is then furnished to a daughter cell in order for that offspring to develop the same characteristics that its mother had and in turn be the replica for making a set of genes for a 3rd generation and so on. This reproductive function of DNA we shall refer to as the genotypic function.

Ten years ago this view of the function of DNA was called the "central dogma." As such, it was the target of intensive critical inquiry and debate. Many scientists focussed on some aspect of its foundation and support that

was absent or shaky. All this effort has so solidified the foundations of our view of how DNA functions in heredity that we have transferred our pre-occupation to other, far less tenable dogmas.

A large measure of support for our concepts of gene action derives from our capacity to alter the genotype of a cell with results that fit predictions with an accuracy often typical of astronomical circuits. For example, we are now able to remove the DNA from a given bacterial species, call it "Donor," and by fractionation procedures separate it into fractions which contain the different genes. Under suitable conditions, a different species, call it "Acceptor," which lacks one or more of these genes, will absorb the DNA, assimilate it into its own genotype and thereby be transformed into a new genotype, a veritable new species. The new species, a mutant of Acceptor, displays the novel character which was donated to it by the DNA of the Donor species and breeds true for countless generations. This is one way to alter the genotype.

Another way to mutate the genotype is by way of X-rays, ultraviolet light and other forms of radiation and by a variety of chemicals like mustard gas. There is now quite an arsenal of these mutagenic agents which produce specific chemical alterations in the DNA. What is the consequence of such an alteration in the DNA? A change at one spot on the DNA is reflected by a change in the particular protein that corresponds to that gene. If you change a letter in a very carefully worded message the chances are very great that the message will be distorted. For example, changing a certain

letter in the DNA of the gene responsible for the protein hemoglobin results in a change in one of the 300 amino acids that comprise hemoglobin. In certain individuals suffering from sickle cell anemia this single amino acid change in their hemoglobin makes it fragile and functionally defective. The disease is fatal in a large percentage of individuals with this defect. In less benevolent societies such individuals would die before mating or be discouraged from doing so. Very rarely a change in a letter of the DNA message will give rise to a distortion in the resulting protein that will have a felicitous consequence. It may give the mutant individual a distinct advantage in thriving or surviving and in reproducing in a given environment. By natural selection this new species is thus favored and a faithful reproduction of members of that favored species is encouraged. This is in essence what evolution of species is all about.

We really don't know the particular agents which have been responsible for the mutations responsible for the evolution of species we see represented on earth today. We're not much better off in assessing the mutagenic agents affecting us in our environment at present. But by the burden of all recent experimental work confirms that given enough time and enough generations, random mutagenic events, followed by natural selection, provides a compelling explanation for the assortment of creatures on the earth. I have often marvelled at the incredible coloring of a butterfly or the architecture of a tendon. These wonders pale by comparison with the even more fantastic complexity and ingenuity in the biochemical processes in

in every cell. But then I realize that as ~~biochemists~~^{Scientists} we've been at this game for ~~less than~~ 100 years whereas nature has been working night and day in every corner of the earth for over a billion years. And simpler forms like bacteria have generation times of 20 minutes rather than 20 years.

I have talked so far about the destiny determined by our DNA. Is there anything we can do to alter the consequences of our hereditary endowment? The influences of the environment are well known to all of us from our experience. It is worth restating that man differs from other creatures in developing a culture which he can provide as a legacy by his writings and other teachings. Fire, the wheel, the computer, language, the atomic concept, morals are easily acquired because they don't have to enter the DNA. But then again they're easily lost too. Among the more profound things that can be done to alter the phenotype that we see in prospect are transplantation of organs or clusters of cells that will develop into organs. Endocrine glands, kidneys might be the kinds of tissues which soon may be used to replace defective or cancerous organs. Drugs will be developed that will do more than alleviate a defect or thwart a microbial invader; these drugs will influence and modify the development of organs which normally cope with this problem. Such drugs may as easily include a modification of the patterns of development of the nervous system as of any other. In this category the use of phenotypic modifiers of a non-medical nature should be cited. Computers will soon be miniaturized to pocket size with rather elaborate programs to facilitate memory and judgment. As an example of what computers can do:

logical

Story of general asking for advice on military decision; answer from computer was "yes." "Yes, what?" Computer answers "Yes, sir."

What I've discussed up to this point indicates that we have a reasonably sound insight into the molecular basis of biological form and function. We also have a reasonably clear grasp of the nature of the evolutionary process and a remarkable capacity to modify and shape species by altering genotypes and phenotypes. So far the areas of major clarification in biology have not included the nervous system of simpler creatures, let alone that of man. *How we gain information from the environment?*

We therefore come to the second question.

2. Are mental processes, despite their complexity, understandable at a molecular level?

Range → *to response*

Why not? Yes. Of course!

I don't underestimate our ignorance of and the complexity of the nature of thought processes, emotional responses, in short, the personality. Yet there are two compelling reasons for assuming that mental processes must be accessible to the biochemist: 1) Without the conviction that this lofty peak can be reached, there will be no assault, and 2) biological processes that appeared to be of comparable complexity have been solved in a relentless fashion, and, I would add, at an incredible speed. Let me illustrate.

Who would have imagined in 1850 that Darwin the naturalist after a long voyage around the world could make the observations, collate them and inter-

pret them in a way that has explained biological and even chemical phenomena ever since? Equally remarkable is that entirely independent of Darwin, at the same time and half a world away in Australia, Wallace formulated a concept of evolution based on natural selection which hardly differed from Darwin's. Even today this feat of Darwin's and Wallace's is an intellectual tour de force that is inspiring.

Closer to home is the history of alcoholic fermentation. Pasteur had established around 1850 that yeast cells were responsible. ~~Harden~~ ~~said in 1900:~~

~~✱The problem of alcoholic fermentation, of the origin and nature of that mysterious and apparently spontaneous change~~ which converts the insipid juice of the grape into stimulating wine, ~~seems to have~~ ^{had} exerted a fascination over the minds of natural philosophers from the very earliest times. ✱

Pasteur, after ~~a life-long study of~~ the most brilliant and perspicacious studies, concluded that the conversion of sugar to alcohol and CO_2 was a vital act, a performance of which only an intact growing yeast cell was capable. In his words:

"The chemical act of fermentation is essentially a phenomenon correlative with a vital act, commencing and ceasing with the latter. I am of the opinion that alcoholic fermentation never occurs without simultaneous organization, development, multiplication of cells or the continued life of cells already formed. The results expressed in this memoir seem to me to be completely

opposed to the opinions of Liebig and Berzelius. If I am asked in what consists the chemical act whereby the sugar is decomposed and what is its real cause, I reply that I am completely ignorant of it."

Then in 1900 quite by accident, Buchner made a clear juice by pressing yeast and upon addition of sugar observed a frothing and foaming and production of alcohol. He wisely recognized that he had discovered alcoholic fermentation in a cell-free system. This was the start of the modern biochemical era. During the first half of this century we saw the process of fermentation clarified as a sequence of about 15 discrete, chemically rational steps leading from glucose $\longrightarrow 2\text{CO}_2 + 2\text{CH}_3\text{CH}_2\text{OH}$ and a net accumulation of chemical energy in the form of ATP that supports the life, growth and multiplication of the yeast cell.

I have never forgotten this lesson from history and the men whose lives have displayed their devotion to it. To restate it, the lesson is simply that words like cell, protoplasm, nucleus and other inventions of the scientist are useful but dangerous. They tend to close an issue by packaging it in a name. Take "protoplasm." What a tragic altar for so many gifted minds and lives even today. We must assume that everything, but everything, can ultimately be described in physical and chemical terms, if not today, then very soon, maybe tomorrow.

~~I remember reading~~ ^{recall reading} ~~the~~ ^{the} ~~around 1945~~ lectures which A. J. Kluver of Delft delivered in 1930. He was a gifted and highly accomplished micro-

biologist and biochemist. Discussing the synthesis of fatty acids he said:

"For I have only to remind you how the conversion of sugar into fat demands for its successful completion a harmonious succession of a special set of primary reactions out of the many that are possible. And the perfect harmony which is the one condition for such a long chain of reactions is the exclusive prerogative of the living cell.--Hence attempts to prepare from microbial cells enzymatic agents capable of bringing about more complicated metabolic processes will be fruitless, because either the harmony required will be ~~disturbed~~ by the methods applied or, if this pitfall is avoided by a very mild treatment of the cell, most other metabolic processes will be maintained as well, with the result that the cells will continue their normal development.

"We will have to resign ourselves to the fact that we will never succeed in proving experimentally the enzymatic character of more complicated metabolic processes."

Yet within ²⁰~~five~~ years, the enzymes of fatty acid oxidation had been isolated and characterized and by 1960 we understood the chemistry of fatty acid ^{synthesis}~~metabolism~~ to the point of being able to reconstruct it in the test tube and chemically rationalize most of its details. On to the next bastion!

Editorial comment in newspapers about the genetic code, viral action, transformation invariably refer to the ongoing revolution in biology. The burden of my argument is that there is no new revolution in the philosophy and practice of biochemistry. F. G. Hopkins eloquently disowned protoplasm 50 years ago. It just requires the courage of our convictions to

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as a result of
acetyl-coenzyme A

reject vitalism in the face of new and seemingly more difficult problems. Twenty years ago Beadle and Tatum, here at Stanford, established in their work with *Neurospora* that there was a clear and causal connection between a gene and a given enzyme. But 10 years ago not even Beadle, who is anything but pessimistic, would have dreamed that today we would understand gene action with such clarity and have techniques and tools to manipulate and shape it. I am astonished to have witnessed what Dr. C. Yanofsky has accomplished in the last 5 years establishing that the linear arrangement of the amino acids in a particular enzyme is spelled out by precisely the anticipated linear arrangement of units in the DNA of the gene which codes for that enzyme.

While the term revolution is not justified, I can't deny that there has been lots of excitement, the pace has quickened and the interest and imagination of physicists and chemists and the intelligent citizen ~~have~~ been sparked by these insights into the chemical basis of heredity.

How about an understanding of the nervous system? Does our ignorance of memory, moods and mental illness indicate that this area of biology is quite another kettle of fish? Of course not! There simply has been relatively little work done on the fine anatomy and the biochemistry of the brain. Very little solid work has been attempted ^{in the} ~~to~~ isolate ^{him} and characterize ^{ation of} the compounds that comprise nervous tissue. There has been relatively little effort toward a basic grasp of the mechanism of energy transfer from ATP to electric current--this is true in the electric eel and of course even more true in the brain. As serious prob^{ing} gets under way,

we can expect new techniques to be developed to meet the demands of novel questions, unusual compounds and bizarre arrangements. New insights will emerge and I know for certain that sooner than I'd conservatively estimate, we'll understand the chemical basis of ^{how} drugs, hormones and emotional stresses influence our behavior.

Einstein We shall ~~understand~~ = We shall understand!
"The eternal mystery of the world is its comprehensibility." Einstein

We come now to the last and perhaps most pertinent question ^{for the Science & Religion people}

3. Even if mental processes and emotions are understood at a molecular level, are science and technology adequate to guide human behavior? Is religion necessary as a guide to the human spirit?

^{Dubos question} Of course there is no scientific formula for solving social, political or artistic questions. It is absurd to expect available scientific methods to govern our decisions in these areas.

Nevertheless I ^{should tell you straight out, I think would,} ~~find~~, as so many of my colleagues ~~do~~, that religion is not necessary for developing a code of ethics and for spiritual and aesthetic pleasures. Rather I find that the practice of science and the attitudes it generates provide great ^{or sufficient} satisfaction for my aspirations. So often it is stated by theologians and occasionally by scientists too that there is no conflict ^{or grief} between science and religion. This simply is not true. The conflict is deep and should be recognized as such.

I would like to describe in general terms the aspirations of the scientist and what I see that of religion to be. In doing this I will ^{borrow} ~~quote~~ liberally and

freely from I. I. Rabi who put this ~~whole~~ matter so nicely in a brief lecture 2 years ago.

A great variety of drives cause men to become interested in science. Their personalities and the cultures from which they come cover the map. Let me discuss first the method of science and then ~~its~~ ^{the} culture ^{of science.} The method of science has many facets. I will emphasize two of its aspirations.

There is the collector and classifier whose concentration might have been in stamps, books or pictures, but as a scientist it is in phases of botany, geology, astronomy or spectroscopy. High talents of intellect and insight can be devoted to these aspects of sciences. The hunt for a new species of virus, a new spectral sequence, a new collection or system of galaxies can be both exciting and demanding. Ingenuity, persistence and some luck are necessary for success and satisfaction in this phase of science. We would be nowhere without this type of person.

Basically, this element of science satisfies more immediately the desire to discover and to know the facts of nature. Nature is a grand and inexhaustible source of wonder and amusement. ~~The person to whom a fact is just a fact may become a mathematician or a logician, but he will never be a true poet or scientist.~~ The scientist, the experimental scientist at least, shares with the poet and artist a feeling for the value ^{of} ~~for~~ the immediate and the variegated face of nature. The geologist loves his bright and shiny stone, the biochemist his new enzyme, the physicist his spectrogram.

In holding a mirror to nature, the scientist satisfies his basic desire or aspiration just to know, to find out, or, with good fortune, perhaps make order out of the otherwise chaotic jumble of immediate experience. It is an aspiration that we all share from childhood. In this sense scientists are just children who never grew up, who never lost the nagging urge to ask how, why, and what. To the chosen few whose lifetime of labor in collecting is crowned by an insight which orders these facts of nature into a simple, meaningful pattern, we pay homage and gratitude.

The other facet of human aspiration which contributes to the method of science is making things. The use of tools, the arts and crafts are not science, but share with science the manipulation of nature. Arts and crafts satisfy the desire for material needs of food, shelter, decoration, armament. Scientific tools are less practical but in the end more powerful. They manipulate nature not for immediate or material ends but for the purpose of providing new knowledge or the tools which could provide new knowledge.

What is the culture of science? Here we share with the poet and artist the delight in immediate empirical experience with its aesthetic, emotional and intellectual values. This experience is expressed, not in the language of the heart, but in a format that is understood without barriers of language, national culture or time. This discipline of reporting scientific experience is a crucial element of the culture.

This manipulation of nature is not directed to useful ends or ends which are said to be useful. There is enough pleasure just in the invention of novel combinations to achieve what had been difficult or impossible.

Our goal is to utilize the tools of present knowledge to gain new knowledge, knowledge which we could never have foreseen or imagined. I don't understand why the scientist's aspirations and satisfactions aren't widely understood. They are, after all, the aspirations which are shared by all thinking and feeling people. There is perhaps one important distinction. Our satisfactions come from broadening and deepening our knowledge and understanding of all phenomena, whereas the rest of mankind concentrates on man. The scientist tries to see the world as it really is or might be shorn of man's excessive preoccupation with himself. Since scientific curiosity includes the nature of man, it will never be satisfied because it will never reach its goal to know all and understand all.

Now for religion. Science and religion have always been in conflict. Since the time of Galileo this conflict has sharpened. Many able men, both from the side of science and of religion, try to reassure you that there is no conflict. Bookstores do a big business with this literature. To synthesize such a bridge only devalues both aspects of a powerful urge of the human spirit.

The urge to comprehend the visible and invisible universe and to find man's place within it is common to both science and religion. In these matters religion has always taken the lead. Questions about man's place

in the universe and his origins had to be given answers in each generation. And they had to be complete answers.

The ancient Hebrews could not wait for the discovery of the neutron and bacteria, or for Darwin, Morgan, Crick and Watson to explain the variety of life and the origins of man and of the universe.

The poetry of the Bible cannot fail to move the most prosaic scientist even today. By dramatic imagery and lofty poetic insight, religions have provided systems that embraced everything. They gave immediate satisfaction to man's yearnings for order in the world, and guidance in his life on earth and his future beyond it. They released him from certain fears, sometimes by substituting new ones. People want very much to believe and religion has exploited this human quality. For a religion or religious system to be fully effective it has always become established in law and custom; the tenets come to be regarded as self-evident.

Religious thought soars like an eagle. Science plods like a bulldozer. Where science has passed anyone can follow. Whereas religion is aristocratic, science is democratic. The bulldozer of science clears a tangled jungle. Sometimes the jungle has had lovely gardens and sentiments. But the ground is always readied for newer and perhaps even more beautiful crops. In any event every individual gets a fresh start.

You hear it said that science gives man knowledge but does not tell him what to do with it. He is supposed to get these insights from religion

or from the so-called humanities. What a pretension! The great writings of the humanist and holy religious writs can inspire men to noble actions; they can also incite him to acts of folly and cruelty.

Science doesn't make such claims. It presents what it knows at the moment and leaves the choice and decision to an informed act of "free will" of the individual or group of individuals. Because science doesn't know all the answers, it cannot prescribe the "correct" choices. It promotes the greatest latitude for individuality in wise choice of alternatives based on available information.

The conflict between science and religion, between science and the humanities, remains. Religion and humanities must always claim more than it knows and, therefore, must always retreat and qualify as science advances. The true humanist and religionist welcomes scientific advance because it also allows him to advance his cause with deeper understanding.

Often, when I read what the humanist says about the scientist I am struck by ^{his} the exaggeration of the methodologic details, the technologic applications, ^{his impression of a overwhelming} the relentless acquisition of scientific discovery. ^{I assume you} There [^] is no battle order march toward a predetermined goal. Quite the opposite.

True scientists traditionally are free and highly individualistic. Each sets his own goals following his interests. Such co-ordination as there is comes out of the nature of the subject matter and out of the tradition of the discipline. Attempts to interfere, direct, or guide this freedom, as in ^{Some industrial organizations or clinical departments or in} some countries with overplanned societies, result in inefficiency and frus-

tration of the creative urge. Scientists are well aware that they are prone to error. He is in constant dread knowing how easily he can misinterpret his observations or miss the essential pearl. The bold speculator can become so fascinated by the beauty and sweep of his hypothesis that he may see it as an end in itself. It must be true, he feels, because it is so elegant. However, nature is the court of highest appeal. It and its scientific servants are relentless, and error cannot survive for long.

Here is one of the greatest appeals of science, an appeal which satisfies one of the greatest of human aspirations -- to be a member of a community which is free but disciplined. Science possesses an infinite variety of limited goals but in toto marches toward a limitless horizon. It consolidates its gains but never rests. There is an inner solidity and optimism in the community which comes from a sense of achievement. There is a deep conviction that the advance of science is important and worthy of the greatest effort. There is fierce competition, there are strongly held convictions, and sharply differing evaluations of one achievement or another. Despite this very human confusion, there is the assurance that with further study will come order and beauty and a deeper understanding.

I am fond of a quotation from Aristotle ~~that puts this so well~~: "The search for Truth is in one way hard and in another easy. For it is evident that no one can master it fully nor miss it wholly. But each adds a little to our knowledge of Nature, and from all the facts assembled there arises

a certain grandeur."

Finally I want to mention one of the greatest rewards of the pursuit of scientific discovery. It must match the revelations of the sanctified. It comes accidentally and is often a matter of luck rather than the result of planning. It may come in an illuminating flash of insight or in the course of an experiment, as when Anderson saw an electron track moving the wrong way and realized he had a positive electron, or when Watson and Crick assembled a model of DNA that fit not only the X-ray diffraction pattern but provided a simple model for genetic replication. Scientists don't write about this rare rapturous moment. It is so different from the everyday routine of research. This fleeting vision in one flash rewards you for months and years of patient and discouraging work. At these times the scientist is filled with profound awe and humility that he should be chosen for this revelation. There is a quality about science, or rather about nature, which is always miraculous in its originality. To obtain a glimpse of this wonder can be the reward of a lifetime.